Meteorological and snow distribution data in the Izas Experimental Catchment (Spanish Pyrenees) from 2011 to 2017

~~In situ observations of meteorological variables and snowpack distribution at the Izas Experimental Catchment (Spanish Pyrenees): The importance of high quality data in sub-alpine ambients.~~

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Abstract: This work describes the snow and meteorological dataset available for the Izas Experimental Catchment~~,~~ in the Central Spanish Pyrenees, from the 2011 to 201~~6~~7 snow seasons. The experimental site is located on~~in~~ the southern side of the Pyrenees between 2000 and 2300 m above sea level, covering~~ with~~ an area ~~extension~~ of 55 ha. The site is a good example of a sub-alpine ~~ambient~~ environment in which the dynamics of snow accumulation and melt~~ing dynamics have~~ are of major importance in many mountain processes. The climatic ~~dataset~~dataset consists of (*i*) continuous meteorological variables acquired from an Automatic Weather Station (AWS), (*ii*) detailed information on snow depth distribution collected with a Terrestrial Laser Scanner (TLS, LiDAR technology) for certain dates ~~along~~ across the snow season (between 3 and 6 TLS surveys per snow season) and (*iii*) time-lapse images ~~that~~ showing the evolution of the Snow Covered Area~~ evolution~~ (SCA). The~~–~~ ~~includes information on different~~ meteorological variables acquired in the ~~with an~~ Automatic Weather Station (AWS) ~~such as~~are precipitation, air temperature, incoming and reflected ~~short~~ solar radiation and ~~long-wave~~infrared surface temperature~~ radiation~~, relative humidity, wind speed and direction, atmospheric air pressure, surface temperature (snow or soil surface) and soil temperature; all were taken~~of them~~ at 10 minute intervals. Snow depth distribution was measured during 23 field campaigns using a Terrestrial Laser Scanner (TLS), and ~~there is also available~~ daily information on~~of~~ the Snow Covered Area (SCA) was also retrieved from time-lapse photography.

The data set (https://doi.org/10.5281/zenodo.848277https://doi.org/10.5281/zenodo.579979) is valuable since it provides high spatial resolution information on the snow depth and snow cover distribution, which is particularly useful when combinedin combination with meteorological variables to simulate the snow energy and mass balance. This information has already been analyzed in variousdifferent scientific studies onworks studying snow pack dynamics and its interaction with the local climatology or terrain topographical characteristics. However, the database generated till the date has great potential for understanding other environmental processes from a hydrometerological or ecological perspective in which snow dynamics play a determinant role.

1. Introduction

The sSnowpack distribution and its temporal evolution have a marked influence onin many mountain processes. For instance,These include erosion rates and sediment transport (Colbeck et al., 1979; Lana-Renault et al., 2011), geomorphological and glaciological processes (López-Moreno et al., 2015; Serrano et al., 2001), and phenological cycles (Liston, 1999; Wipf et al., 2009) are directly controlled by the evolution on time timing of snow distributioncover over time. InOn the other hand, snow melting dynamics areis also ofhas major importance from a hydrological perspective since one-sixth of thetotal Earth's total population depends on the water storage in mountain rivers headwaters (Barnett et al., 2005). In downstream areas exposed to extreme climatic conditions, the snowmelt runoff from mountain areas becomes a key element -(Viviroli et al., 2007), especially in these zones affected by water shortages.subjected to water scarcity. SuchThis is the case of semi-arid regions, likeas the Mediterranean area, which is characterized by an irregular climate with long drought periods (Vicente-Serrano, 2006), and thereforeby its dependence it is highly dependent on water stored in mountain areas, such as the Pyrenees is quite high (López-Moreno, 2005; López-Moreno et al., 2008).

The Pyrenees are a mid-latitude mountain range, with significant snowfalls in the more elevated presence in high elevation areas throughoutalong the year. During the boreal spring, Pyrenean river discharges depend on the snow–melt melting of snowtiming, directly accounting from snow aboutwith approximately 40% of spring runoff being directly attributable to snow (López-Moreno and García-Ruiz, 2004). Thus, snow accumulation has a heavylarge influence on Pyrenean headwaters. This dependence is mostlyrather due to the generally continuous snow cover from November to April above 2000 m above sea level (a.s.l.) (Alvera and Garcia-Ruiz, 2000; García-Ruiz et al., 1986; López-Moreno et al., 2001). This way and, therefore, the study of the snowpack atin high elevations areas of in the Pyrenees is crucial for understanding and managing mountain river discharges (López-Moreno, 2005), especially in the scenario offrame of a global climate change scenario (García-Ruiz et al., 2011). However, the existence of continuous snow observations above 2000 m a.s.l. is scarce in this mountain range, sincebeing most of them only have informationavailable from 1600 to 2000 m a.s.l. and when available these observations spam span those that are available only cover short time spans.periods. Therefore,by well-established study areas atin high elevations with, having continuous measurements of meteorological variables and snowpack distribution are required in the Pyrenees.

In tThis paper, it is presentsed the recently acquired dataset of meteorological and snowpack variables obtained fromin a small size experimental catchment onof the southern facesside of the Pyrenees. Although meteorological and hydrological data are available fromsince previous years (some variables have beenwere measured since the late 1980s80's (Alvera and Garcia-Ruiz, 2000)), we presentoffer data from the 2011/12 to 20152016/176 snow seasons, as data series providehave higher quality and continuity, and also they match with in situ observations of snow depth and snow cover. The dataset consists of (*i*) continuous meteorological variables acquired from an Automatic Weather Station (AWS), (*ii*) detailed information on snow depth distribution collected with a Terrestrial Laser Scanner (TLS, LiDAR technology) for certain dates acrossalong the snow season (between 3 2 and 6 TLS surveys per snow season) and (*iii*) time-lapse images that showing the Snow Covered Area evolution (SCA). Some years of this dataset haves already been used to study the topographic control on snow depth distribution (Revuelto et al., 2014b), the spatial variability of snow-pack at different distances (López.Moreno et al., 2012) or to investigateing how detailed snowpack simulation could be improved by including snow distribution information (Revuelto et al., 2016a,b).

The paper is structured as follows: Section 2 describes the study area characteristics; Section 3 presents meteorological data acquired from the AWS with a general description of the observed climatology; Section 4 describes the distributed measurements on snow depth distribution from the TLS and the SCA derived from time-lapse images; Section 5 concludes with information for downloading the database; and finally Section 6 summarizes all information available and the potential application of the database

2. Study area characteristics and climatology

2.1. The Pyrenees

The Pyrenees lies onin the northeastern borderlimit of the Iberian Peninsula (Figure 1) and form. It is an orographic barrier between the north and south faces. This way a Due to this, progressively higher aridity is found toward the southsouthward as a consequence of the mountain range blocksing humid air masses from the Atlantic

(López-Moreno and Vicente-Serrano, 2007; Vicente-Serrano, 2005). Thus, the natural barrier directly influences precipitation, leading toand as a consequence areas above 2000 m a.s.l. receivinge about 2000 mm/year, increasing to 2500 mm/year– in the highest divides of the mountain range and rapidly decreasinge to 600-800 mm/year in low elevation areas onf the southern side (García-Ruiz, et al., 2001).

Another distinct feature of the Pyrenees is their location between two water masses with contrastinged conditions; i.e., in the western side is the Atlantic Ocean is on the west side, while in the east side lays the Mediterranean Sea lies in the east. This positionsituation between both water masses causesoriginates a climatic transition from Oceanic to Mediterranean conditions intoo the east. During autumn, fronts approaching from the Atlantic bring the highest monthly averages of precipitation in the western observatories, reaching the with their total contribution accounting forof all these fronts a 40% of total annual precipitation in this area (Creus-Novau, 1983). OppositelyConversely, spring and summer storms mostly affect the eastern areas of the Pyrenees, being favoredpromoted by the development of zones where sea breezes and local winds convergence zones that to initiate deep moist convection along the eastern fringe of the Iberian Mediterranean area (Azorin-Molina et al., 2015). Therefore,by Pyrenean observatories in the east record a large numberhave a major contribution of convective events; e.g., reaching ai.e up to 32% of total annual precipitation in eastern valleys, but and dropping below 16% of annual precipitation in western valleys (Cuadrat et al., 2007). In early winter, the arrival of fronts from the northwest and west are the most frequent, leading to the highest snow accumulation being found in the western Pyrenees (Navarro-Serrano and López-Moreno, 2017). The Azores high, which usually affects the Iberian Peninsula for at certain times in thesome winter periods, originatesgives rise to relatively long periods with no snow accumulation in this season. Subsequently, in spring, snow accumulation isare associated with southwesterly advections, which lead to highheavy snow accumulations in the western Pyrenees (Revuelto et al., 2012). Snow remains for long periods above 1600 m a.s.l., between November and April (López-Moreno and Nogués-Bravo, 2006).

Similarly to precipitation, air temperature is influenced by the Atlantic-Mediterranean transitions, but elevation plays a major role inon its distribution. For instance, the lower annual thermal amplitude is observed in the western Pyrenees is because of the proximity of the ocean proximity (Cuadrat et al., 2007). As a general tendency in the

Central Pyrenees, the annual 0ºC isotherms lie~~lays~~ between 2700 and 2900 m a.s.l. (del Barrio et al., 1990; Chueca, J., 1993).

Additionally the Pyrenees exhibit a high inter-annual variability in air temperature and precipitation, which makes~~involve great uncertainty in~~ the annual snow accumulation very uncertain (López-Moreno, 2005). This variability is influenced by the inter-annual variability of atmospheric circulation, ~~being identified~~with ~~–~~a decrease of snow accumulation weather types being identified under positive North Atlantic Oscillation (NAO) phases (López-Moreno and Vicente-Serrano, 2007). As observed with precipitation, snow accumulation correlates to~~with~~ Atlantic-Mediterranean proximity and distance from~~to~~ the main divide of the mountain range (Revuelto et al., 2012), and is strongly dependent on the fluctuations of the 0ºC isotherm during winter and spring. This high climatic variability is also the cause of~~originates a~~ large inter-annual variability in total snow accumulation and ~~on~~ its temporal distribution across~~along~~ the snow season (López-Moreno, 2005).

2.2. The Izas Experimental Catchment

The Izas Experimental Catchment (42°44′ N, 0°25′ W) has a surface area of 33 ha, but snow depth information covers a total of 55 ha, with elevations ranging between 2075 and 2325 m a.s.l. This area is close to the main divide of the Pyrenees in the headwaters of the Gállego River, near the Spain–France border (Figure 1). The Izas Experimental Catchment exemplifies the general characteristics of sub-alpine areas of the Pyrenees. In this environment, snowpack dynamics are of~~have a~~ major importance throughout~~along~~ the year. Thus the atmosphere-snowpack interactions observed at this experimental site will enable a~~to~~ better understanding of many processes in~~of~~ sub-alpine areas.

The mean annual precipitation is 2000 mm, and snow accounts for approximately 50% of total precipitation (Anderton et al., 2004). For an average of 130 days each year the mean daily air temperature is below 0 ºC, with a mean annual air temperature of 3 ºC, (del Barrio et al., 1997). Snow covers a high percentage of the catchment from November to the end of May (López-Moreno et al., 2010). Lithology shows limestones and sandstones of the Cretaceous period, and limestones of the Paleocene, much more resistant to erosion. The ~~Z~~zonal vegetation type corresponds to a high mountain steppe, mainly covered by bunch grasses, namely *Festuca eskia*, *Nardus stricta*, *Trifolium alpinum*, *Plantago alpine* and *Carex sempervirens.* Rocky outcrops dominate ~~in~~ the upper and steeper slopes (less than 15% of the study area). There are no~~t~~ trees present in the study area. The catchment is predominantly east-facing, with some areas also facing north or south. The mean slope of the catchment is 16° (López-Moreno et al., 2012), with the topographic characteristics displaying~~having~~ the typical high spatial heterogeneity ~~on its topographic characteristics~~ of sub-alpine areas, ~~having~~ with flat concave and convex areas.

3. Meteorological data

The study site is equipped with an AWS located in the lower elevation of the catchment (42º 44’ 33.65’’N, 0º 25’ 8.83’’W, 2113 m a.s.l., Figure 1), located in a flat open area with sparse vegetation (mountain pastures). The AWS measures wind speed and direction, atmospheric air temperature, relative humidity and air pressure, soil temperature for 0 cm, 5 cm, 10 cm and 20 cm, temperature of the surface close to the AWS (snow or soil, depending on whether~~if~~ snow is present or not), global and reflected solar irradiance, snow depth and precipitation (the precipitation gauge is located at 15 m ~~of~~ from the AWS tower) (see Figure 2). Information on the main atmospheric variables has been recorded since the end of 2011 (AWS installed on November 2011). Therefore, data availability covers five complete snow seasons. Since the station is located in the lower elevation of the catchment and despite air temperature lapse rate with elevation, the AWS records serve to describe~~average~~ the evolution of atmospheric variables occurring at the Izas Experimental Catchment.

The data acquisition system consists of a Campbell Scientific CR3000 datalogger that samples each instrument and stores data at 10-minute time intervals. All data is transmitted via modem to the Pyrenean Institute of Ecology where~~and once received we apply some~~ automatic quality-control checks are applied to remove~~for removing~~ outliers. Data gaps are rare for almost all variables and, therefore, instead of gap-filling with interpolation methods, only measured data are available. However, some variables had long data gaps and certain~~thereby some~~ periods have been discarded from~~for~~ further analysis. This is the case of precipitation for the first three snow seasons, which were useless because of the length of data gaps.

Since the main application of the data collected by the AWS is to assess~~the assessment of~~ the ~~snow cover~~ evolution of snow cover in the study area, in the following subsections we focus our analyses on the accumulation and melt~~ing~~ periods: i.e., accumulation (January, February and March; JFM) and melt~~ing~~ (April, May and June;

AMJ).~~ periods~~ Annual values observed during a whole snow season are also presented for each sub-section.

3.1. Wind speed and direction

The AWS is equipped with a Young wind monitor – ALPINE MODEL Young Company, Model 05103-45-5, Wind Monitor –Alpine Model specifications © 2010)~~(Young Company, Model 05103-45-5; http://www.youngusa.com/Brochures/05103-45%20(0613).pdf)~~, placed at~~in~~ the highest point of the meteorological tower (8 m above the ground). The Pyrenees are commonly affected by strong westerly to northerly winds as shown in the wind roses displayed in Figure 3. With the exception of south winds that mainly occur~~ring~~ during the melt~~ing~~ period, westerly to northerly winds dominate. Additionally, ~~the~~ the most frequently~~frequency of~~ moderate to strong winds come from the north-west..~~ winds mainly occurs for northwesterly winds~~.

3.2. Air temperature, relative humidity and atmospheric air pressure

Air temperature and relative humidity were~~are~~ measured with the HMP155 Vaisala sensor (Vaisala Company, HMP155 Humidity and Temperature Probe specifications © 2012~~http://www.vaisala.com/Vaisala%20Documents/Brochures%20and%20Datasheets/HMP155-Datasheet-B210752EN-E-LoRes.pdf~~), and atmospheric air pressure was~~ is~~ recorded with the BP1 sensor from Adcon telemetry (Adcon Telemetry Company, BP1 Barometric Pressure Sensor specifications, © 2015 ~~http://www.adcon.com/download/leaflet-bp1-barometric-pressure/~~). The HMP 155 humidity and temperature probe was~~is~~ placed inside a standard radiation shield ~~and~~ at 3.2 m from the ground in order to prevent~~avoid that~~ the snowpack from eventually covering~~s~~ the sensors.

~~Along~~Over the ~~five~~ six snow seasons analyzed, the mean annual air temperature ranged between 5.26ºC (2014/15~~ snow season~~) and 3.51 ºC (2012/13~~ snow season~~), with an average value of 4.59~~63~~ ºC. ~~The accumulation period has shown a~~ The mean air temperature in the accumulation period~~that~~ ranged from -2.78ºC (2012/13) to -0.56ºC (2016/17)~~-1.15 ºC (2011/12 snow season)~~,~~ being -1.79 ºC the~~ with an average value of -1.79ºC for the whole study period. Finally, the melt~~ing~~ period returned~~showed~~ a mean value of 5.5~~1~~6 ºC ranging from 2.79 ºC (2012/13~~ snow season~~) to 7.58ºC (2016/17)~~to 7.30 ºC (2014/15 snow season)~~). Table 1 shows that the 2012/13 snow season was the coldest in~~one of~~ the study period. Figure 4 depicts the temporal evolution of air temperature and other variables observed in the AWS from 2011 to 2016. Thus, this figure shows the control points for~~of~~ air temperature on the ground and the surface temperature.

The relative air humidity and the atmospheric air pressure are shown in Tables 2 and 3, respectively. The mean annual value of the relative humidity for the five seasons is 65%, with ~~a 71~~67% during the accumulation period, and 66~~9~~% during the melt.~~ing one.~~ Similarly, atmospheric air pressure has a mean annual value of 791 mb, with 78~~9~~7 mb~~being~~ for the accumulation period ~~789 mb~~ and 792~~88~~ mb for the melt.~~for the melting period 788 mb.~~

3.3 Ground temperature

On 22 November 2012 four Campbell Scientific "107 temperature probes" (Campbell Scientific Ltd. 107 temperature Probe, © 2012~~https://s.campbellsci.com/documents/es/manuals/107.pdf~~) were installed in the AWS to measure ground temperature at different depths. One sensor was located in the atmosphere-ground interface (slightly buried, 0 cm depth), while the other three were ~~respectively~~ placed at depths of 5 cm, 10 cm and 20 cm.~~ depths.~~ Table 4 and Figure 4 show the average values of ground temperatures and the temporal evolution of ground temperature. ~~There exists a lack of d~~Data is lacking from ~~a~~August 2016 onwards because temperature probes were damaged by cows. The average values during the period with information for the 0 cm, 5 cm, 10 cm and 20 cm depths are respectively: 5.26±6.22 ºC, 4.97±5.52 ºC, 4.93±6.17 ºC, 4.89±4.56 ºC.

The temporal evolution of air and ground temperatures depicts the impact of the snowpack~~ presence~~ on ground energy dynamics. The snowpack shelters ground from the high temporal variability of air temperature. Therefore, the daily variability in ground temperatures ~~have a~~ is significantly lower~~smooth decrease in the daily variability~~. ~~Additionally, it is observed how the~~Furthermore, the different ground temperatures tend to reach 0ºC while snow covers the ground; i.e., the typical soil-snow interface temperature.

3.4. Surface temperature

~~At the same date of~~Together with the installation of the ground temperature sensors, an IR100 infrared remote temperature sensor (Campbell Scientific Ltd, IR100/IR120 Infra-red remote temperature sensor, © 2015~~Campbell Scientific, https://s.campbellsci.com/documents/eu/manuals/ir100_ir120.pdf~~) was also set up to

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measure surface temperature of near target ground or snow. ~~On~~ Table 5 shows~~is shown~~ the average land surface temperatures. The mean annual surface temperature is 2.56ºC, with a mean value of -4.58~~1~~ºC during the accumulation period and 3.~~27~~94ºC during the melt~~ing~~ period.

The infrared remote sensor shows the tendency of the snow surface ~~tendency~~ to cool~~ing~~ faster than soil. During winter and spring, while snow is present on the ground, the differences between air and surface temperature are more marked, with surface temperatures always observed to be lower~~air temperature and surface temperature shows higher differences, being always observed lower surface temperatures~~ (see the occurrence of snow below the AWS when lower surface temperatures are observed in Figure 4). This ~~is~~ plainly exemplifies~~ying~~ the higher energy irradiance of snow when compared to ~~free~~ snow-free soils.

3.5 Global and reflected solar irradiance

The AWS also obtains information on the global and reflected solar irradiance with a CMA 6 Kipp&Konen albedometer Kipp & Zonen, CMP/CMA series pyranometer and albedometer ©, 2015) ~~(http://www.kippzonen.com/Download/72/Manual-Pyranometers-CMP-series-English)~~placed at 3.4 m height. Figure 4 shows the daily evolution of the values recorded, and how these are interrelated, with~~ increasing~~ the reflected radiation increasing at the same time as the incident.~~when incident does.~~ The average values of these variables are presented in Table 6. For the whole period, the average values of the incident radiation are 207.97 W/m^{2}day, taking complete snow seasons into account~~considering complete snow seasons~~, 164.73~~161.15~~ W/m^2 day afor~~ecounting~~ accumulation~~ periods~~, and 280.95 ~~276.93~~ W/m^{2}day for~~considering~~ all melt~~ing~~ periods. Similarly, the reflected radiation average values are: 83.67 W/m^{2}day for entire snow seasons, 109.69 ~~109.57~~ W/m^{2}day for the accumulation ~~periods~~ and 117.06 ~~119.57~~ W/m^{2}day for melt~~ing~~ periods.

Similar~~ly~~ to ground and surface temperatures, the radiation reflected is heavily~~markedly~~ influenced by the presence of snow.~~ presence. Periods in which~~When snow covers~~is present over~~ the ground, the sensor shows higher values of reflected radiation in comparison with~~when compared to~~ snow-free periods (Figure 4).

3.6 Snow depth and precipitation

The AWS is also equipped with a Campbell SR50A sonic ranging sensor (~~Campbell Scientific SR50A,~~ Campbell Scientific Ltd, SR50A Sonic Ranging Sensor, © 2011~~https://s.campbellsci.com/documents/cr/manuals/sr50a.pdf~~). For the sake of

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simplicity we will refer to it as a snow depth sensor, since it is used for measuring ~~how evolves~~ the changing distance between the surface and the sensor (the sensor is placed 2.64 m from the ground, and the ~~being obtained~~ snow depth obtained by subtracting ~~to his~~ this value from the observed distance). This sensor ~~has~~ worked ~~without any~~ uninterruptedly~~ion~~ during the study period and provided~~s~~ a good ~~climatology~~ record of the snow depth evolution in the Izas Experimental Catchment. Therefore, the information on~~f~~ the snow depth can be used as a reference for other observations of snowpack evolution. The average values for the whole study period are: ~~89.20~~93.4 cm for the accumulation period and 47.8~~53.32~~ cm for the melt~~ing~~ period (Table 7 shows the seasonal values). The temporal evolution of the snow depth is shown in Figure 4.

In addition,~~Additionally~~ Figure 4 shows the precipitation values for the period with ~~consistent~~ data in the precipitation gauge (~~since~~from the end of~~end~~ July 2014). The sensor installed is a Geonor T-200B with wind shield (Geonor A/S, geonor T-200B series All-weather precipitation gauges, © 2010~~http://www.geonor.com/brochures/t-200b-series-all-weather.pdf~~), which continuously weights the accumulated precipitation (liquid and solid). The height of the gauge orifice is 3.25 m (2.5 m metal pedest~~ri~~al plus the height of the T-200B inlet). The precipitation accumulated over a certain period was~~is~~ calculated by subtracting final and initial weighted values. Table 7 includes the accumulated precipitation for the whole snow year and also during the accumulation and melt~~ing~~ periods.

4. Information on snow distribution

4.1. TLS acquisitions of snow depth distribution

During the five snow seasons presented here, from three to six TLS surveys were carried out~~accomplished~~ each year in the Izas Experimental Catchment. TLS are devices ~~that use~~using LiDAR technology~~ies~~, a remote sensing method ~~that~~to obtain~~s~~ the distance between a target area and the device. During a TLS data acquisition, the device measures the distance of some hundreds of thousands of points within the area defined by the operator, creating a cloud of data points representing the topography of the target surface. The device used in this study is a long-range TLS (RIEGL LPM-321 (Fig.2), RIEGL Laser Measurements, LPM-321 ©, 2010~~http://www.riegl.com/uploads/tx_pxpriegldownloads/10_DataSheet_LPM-321_18-03-2010.pdf~~). The technical characteristics of this model are: (i) light pulses of 905 nm wavelength (near-infrared), appropriate for acquiring data from snow cover (Prokop, 2008); (ii) a minimum angular step width of 0.018°; (iii) a laser beam divergence of 0.046°; and (iv) a maximum working distance of 6000 m. In order to reduce topographic shadowing (note that terrain topography limits the line-of-sight of the TLS) two scanning positions (Scan station on Fig.1) were established within the study site (Figure 1). ~~Additionally~~ 12 reflected targets were also fixed on~~on~~ the terrain (Fig. 2). The location of these targets was acquired on each TLS acquisition date, since this information is used in the post-processing phase for comparing the point clouds acquired on~~in the~~ different dates. The protocol for obtaining the information in the field and the methodology for generating the snow depth distribution maps for the different TLS survey dates is fully explained in Revuelto et al., 2014a. The method is mainly based on calculating the elevation difference between the point clouds obtained on different dates with and without snow cover~~presence~~ across~~over~~ the study area. The final products are snow depth distribution maps with a grid size of 1x1 m, with a mean absolute error of 0.07 m in the ~~obtained~~ snow depth values (Revuelto et al., 2014a).

Figure 5 shows the snow depth maps obtained for the 2012/13 snow season. ~~It is presented t~~ The information for~~of~~ this snow season is presented because six TLS surveys were completed.~~achieved.~~ Furthermore,~~Additionally~~ the accumulated snow depths were significant~~quite important~~ and thus provide~~reproduce~~ an interesting example of snowpack evolution over~~on~~ time. These maps show the high spatial variability of the snowpack within the study area, with marked changes in the snow depth distribution within short distances. ~~Also it is~~It was also observed how high accumulation areas had~~ve~~ large~~important~~ accumulations during the whole snow season, with a thick snowpack for dates on~~in~~ which the snow cover had already~~ve~~ completely melted over ~~large~~wide areas of the catchment.

Table 8 presents the average snow depth and the maximum snow depth value observed for each TLS acquisition. ~~It is also shown in t~~This table also shows the coefficient of variation on each snow distribution map and ~~also~~ the fraction of the snow covered area. The values obtained depict the heavy accumulation of snow~~important snow depth accumulation occurring~~ in some areas of the catchment, while the average snow depth is lower.

4.2. Snow covered area from time-lapse photographs

The Izas Experimental Catchment is also equipped with a Campbell CC640 digital camera (Campbell Scientific Ltd, CC640 Digital Camera, ©

2010https://s.campbellsci.com/documents/sp/manuals/cc640.pdf). This camera was mounted onwith a solid metal structure set into the ground withfixed in the terrain with concrete (Figure 2)., which Hereby it is ensured a constant position to obtain consistent information.that gives consistency to the information obtained. The digital camera has a resolution of 640x480 pixels with a focal length of 6-12 mm. The field of view of the photographs obtained with the camera mounted onin the metal structure covers approximately 30 ha (Figure 1), whichat represents about a 52% of the total surface covered by the TLS. The camera obtaineds three pictures per day (time-lapse photography) at 10:00, 11:00 and 12:00 UTC, ensuring a good illumination of the area. Figure 6 containsshow four photographs fromobtained during the 2012/2013 snow season, in which can be observedshowing how the snow covered area evolved in time.

The pictures obtained can be projected into a Digital Elevation Model (DEM) of the study site. Projecting the pictures into the 1x1 m DEM foralong an entire snow season provides distributed information on the evolution of the snow covered area evolution in the same reference system asof snow depth maps. The approach for projecting the pictures into the DEM is described by (Corripio, 2004) and the specific features of the methodology applied in the Izas Experimental Catchment are fully described in (Revuelto et al., 2016a). The routines applied first makedoes, in first term a viewing transformation consideringallowing for the optics of the camera and, in second, term a perspective projection, providing a virtual image of the DEM. Therefore, in the second step, the correspondence of ground control points within the surveyed area with the pixels of the photograph must be established. Since this stage is quite sensitiveble, the coordinates of ground control points were acquired with a differential GPS. With this process, images projected images into the DEM had a 3.3 pixel's performance in the calibration of the transformation. Finally, the daily series of the projected images can be definitely binarized to create daily snow presence/absence maps. This information can also be used for other applications, such as as for example to observe the growth timing of plant species.

Since the binarized snow presence/absence maps were recorded onhave almost a daily frequency (note that about a 20% of all photographs from the camera had to be discarded because cloud or snow presence obscureding the camera lens), many parameters can be derived from this information, including the Snow Covered Area temporal evolution, the numbers of days with snow presence or the melt out date

(MOD) on each pixel. Figure 7 shows an example of the number of days with snow presence for the 2011/12 and 2012/13 snow season.

5. Data availability

The database presented and described in this article is available for download at Zenodo (Revuelto et al. 2017; https://doi.org/10.5281/zenodo.848277https://doi.org/10.5281/zenodo.579979). Meteorological data of the AWS are given ready in .csv format. The meteorological dataset includes observations atin 10-minute min intervals. . For an easier transferability and also to allow a wider post-processing, tThe TLS survey point clouds containing the snow depth distribution are available on-line (one file for each TLS acquisition). These files are in ASCII format in the UTM 30T North coordinate system.These point clouds are in the UTM 30T North coordinate system. It is also provided the DEM of the study area in same coordinate system. Cloud-free day photographs from the time-lapse camera are available in the online repository, with the correspondence of pixel-ground control points to GPS coordinates. Information on the optics and chip size of the camera is also provided. Additionally all available Melt Out Date distribution maps (MOD, last Julian day with snow presence on each pixel) are included in the database.

Código de campo cambiado

6. Summary

The Izas Experimental Catchment is a well-established study area onin the south face of the Pyrenees, in which different meteorological and snow variables are automatically acquired. Additionally, an importantgreat effort has been made on field data acquisition with TLS has been conducted during over the last five snow seasons and is ongoing.still maintained. The dataset described here is novel in the Pyrenees because, it represents for the first time, it represents high spatial resolution information on the snowpack distribution and its evolution inon time, as well as making being also available continuous information available on meteorological variables. The high quality of the information obtained has already been already exploited for different studies on the understanding of snowpack dynamics and on the improvement of simulation approaches toof snowpack evolution in mountain areas (López-Moreno et al., 2012, 2014, Revuelto et al., 2014b, 2016a, 2016b). However, there exist many scientific questions still go unanswered, such as the long term influence of topography on snow dynamics, the spatial distribution of snow during precipitation and strong wind ~~blowing~~ events. Also, the high inter-annual variability of snow accumulation in the Pyrenees has serious~~important~~ consequences for water management, especially in the Mediterranean area (García-Ruiz et al., 2011). Thus, it is ~~quite~~very important to continue obtaining information on snowpack evolution and ~~on~~ the meteorological variables ~~that~~ controlling snow dynamics. This information will allow ~~to~~ the scientific community to better understand processes involved and ~~allowing a~~make for better adaptation to climate change scenarios. Moreover, offering the possibility of exploiting the information to other fields~~colleges~~ provides, as INARCH does, the opportunity of establishing new collaboration networks to push forward the frontiers of science ~~limits~~ in mountain areas.

7. Acknowledgments:

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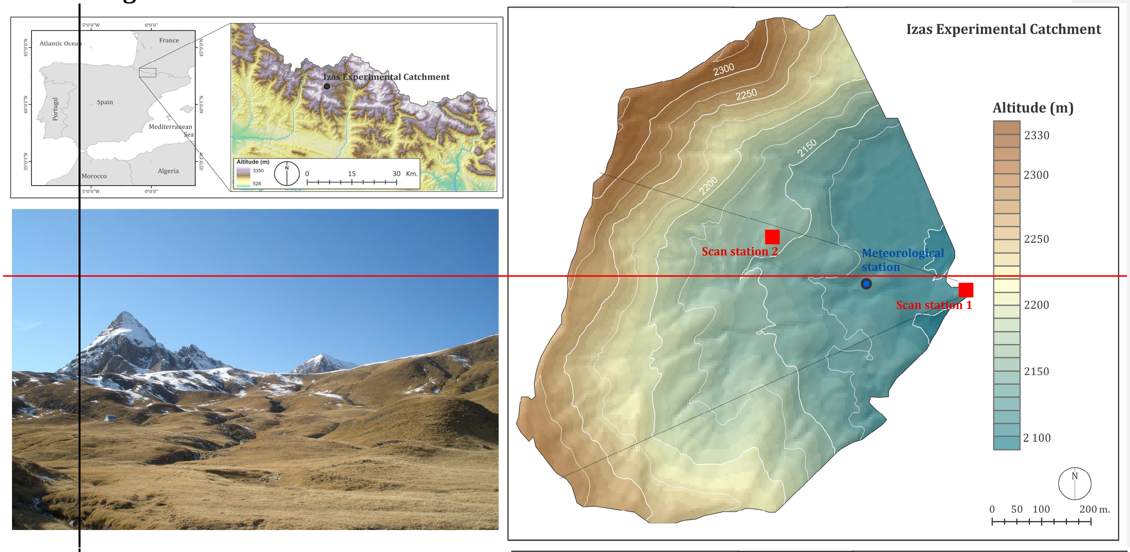
Figures



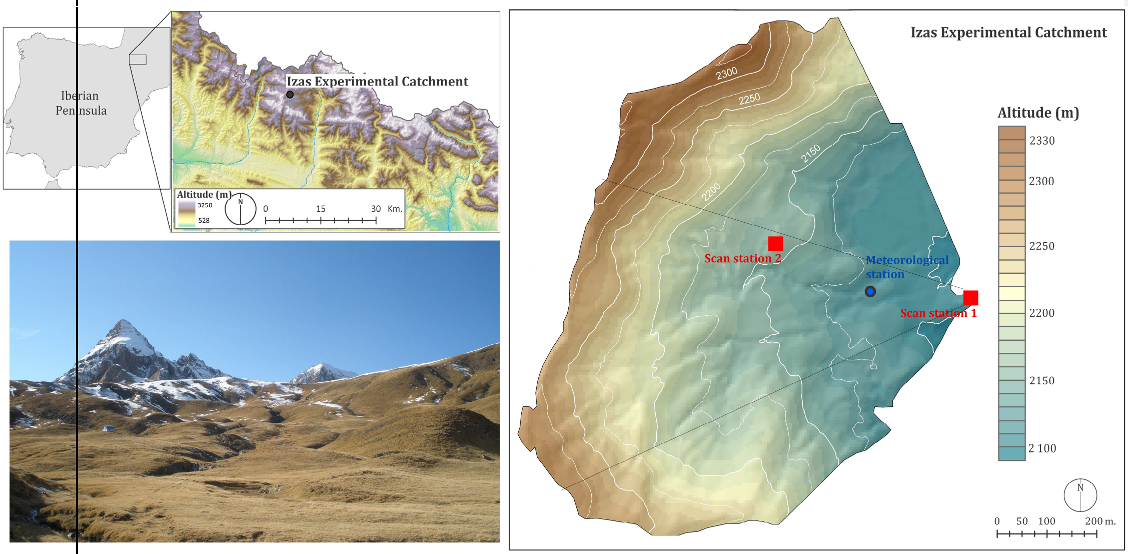


Figure 1: The Izas Experimental Catchment study site. Upper left figure shows the location of the study site. In the lower left panel~~, it~~ is shown an overview ~~picture~~ of the catchment with marginal snow presence. The right map shows the topographic characteristics of the catchment and the location of the TLS scanning positions (Scan stations), the meteorological station and the field of view of the time-lapse camera (continuous lines from Scan station 1).

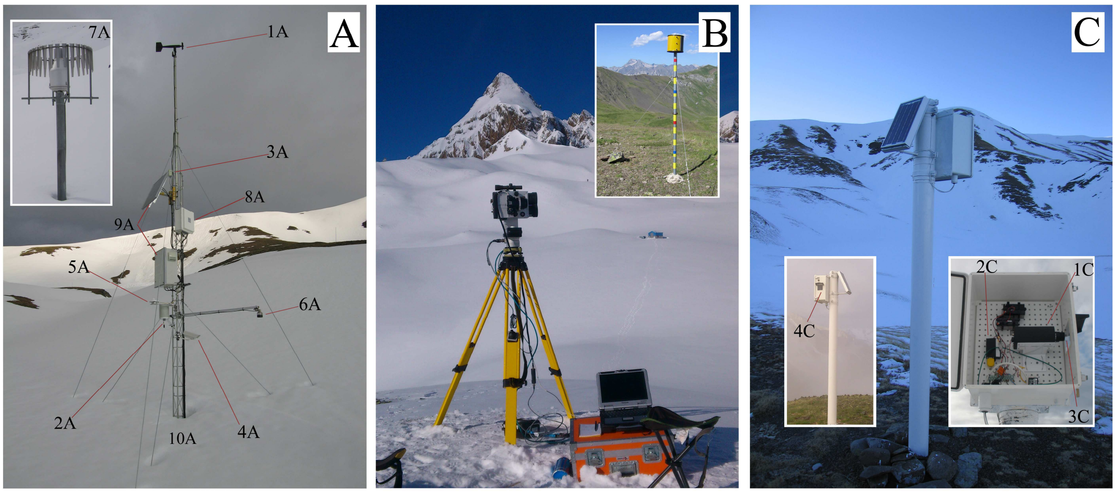
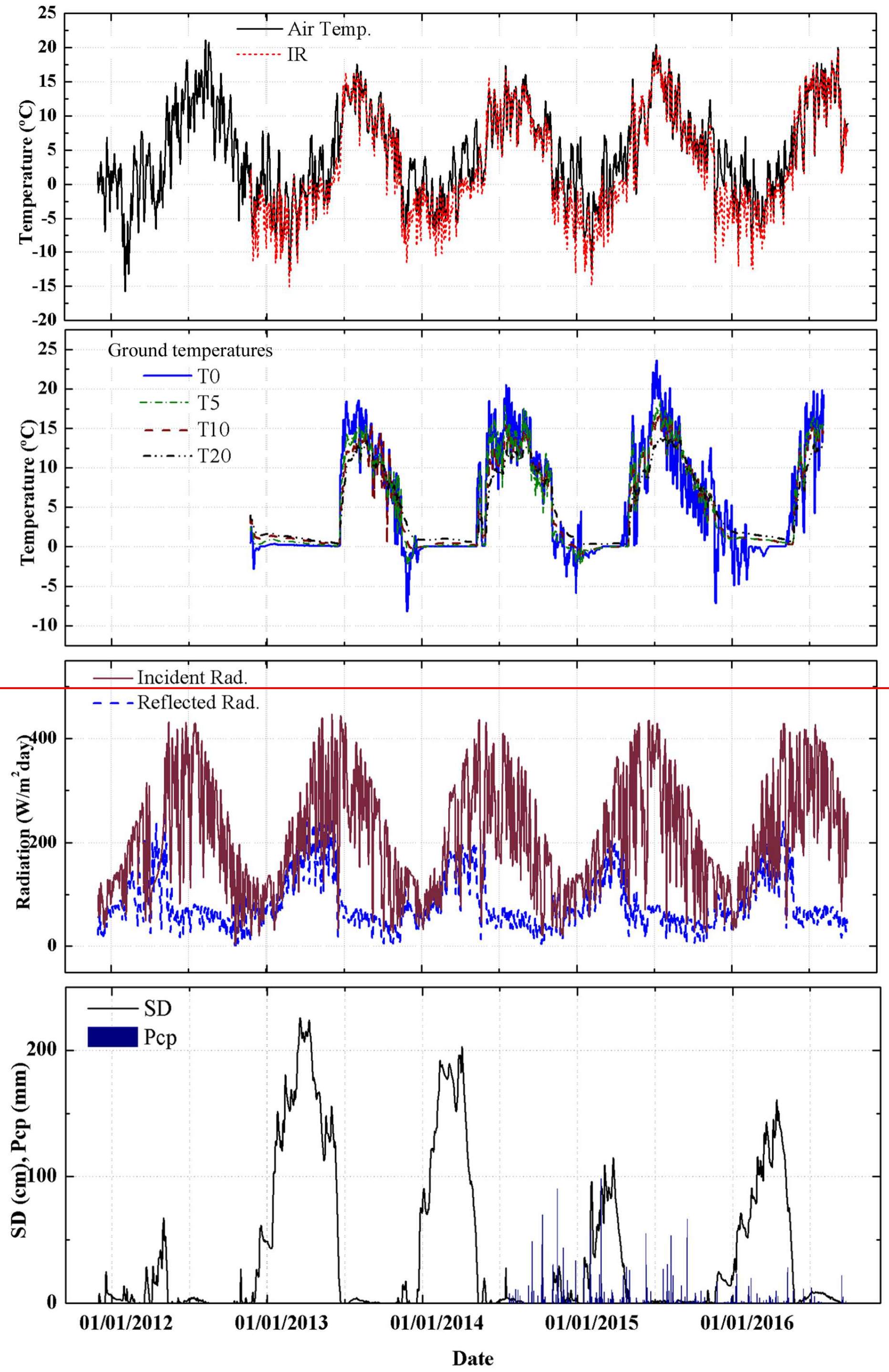


Figure 2: Pictures of the experimental site equipment. (A): AWS sensors. 1A: Young Wind Sensor, 2A: Radiation shield with HMP 155 humidity and temperature probe, 3A BP1 air pressure recorder, 4A: IR100 infrared remote temperature sensor, 5A: CMA6 Kipp & Konen albedometer, 6A: SR50A range sensor, 7A: Geonor T-200B with wind shield, 8A: CR3000 datalogger and modem, 9A: Solar panel and battery, 10A: Campbell Scientific 107 ground temperature probes. (B) RIEGL LPM-321 TLS mounted on~~in~~ the tripod during an acquisition campaign. ~~In t~~The upper-right part ~~it is~~ shows~~n~~ one of the 12 fixed reflective targets fixed on the terrain. (C) Campbell CC640 camera mounted in the metal structure. 1C: digital camera inside the enclosure house, 2C: modem, 3C: protection glass of the digital camera, 4C: frontal view of the camera and its structure.

Figure 3: Wind roses showing the frequency (in %) of wind speed and direction observed in the AWS for accumulation (upper wind roses) and melt~~ing~~ (lower wind roses) snow seasons.



Air Temp.
IR
Temperature (ºC)
Ground temperatures
T0
T5
T10
T20
Temperature (ºC)
Incident Rad.
Reflected Rad.
Radiation (W/m²day)
SD
Pcp
SD (cm), Pcp (mm)
01/01/2012
01/01/2013
01/01/2014
01/01/2015
01/01/2016
Date

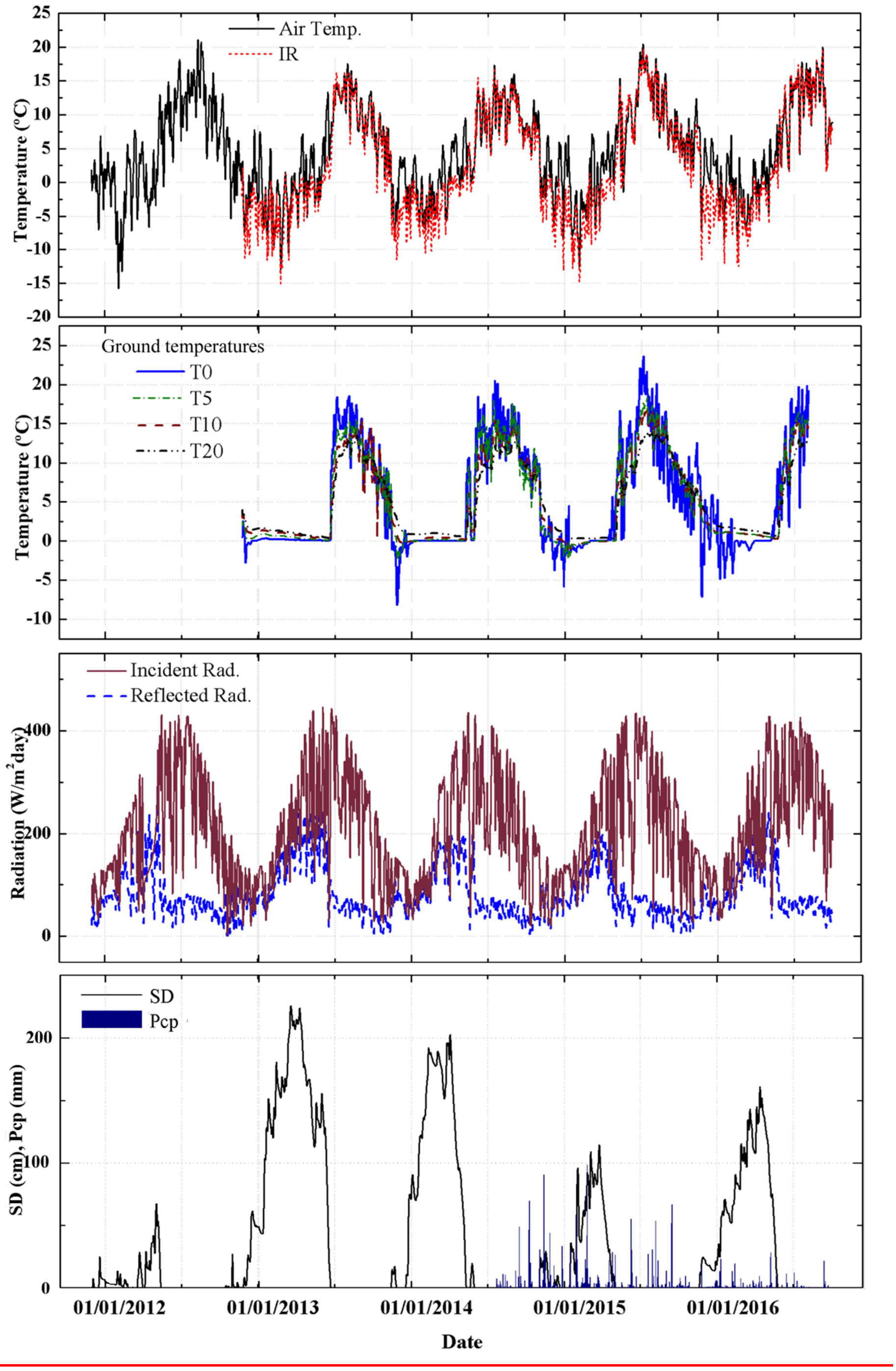


Figure 4: Temporal evolution of meteorological variables during the study period. From top to bottomup panel to the low panel is shown is air temperature and surface temperature (from the IR sensor); ground temperature for the four depths; global (Incident) and reflected solar irradiance; and punctual snow depth (SD) and daily accumulated precipitation (Pcp) (sum of solid and liquid).

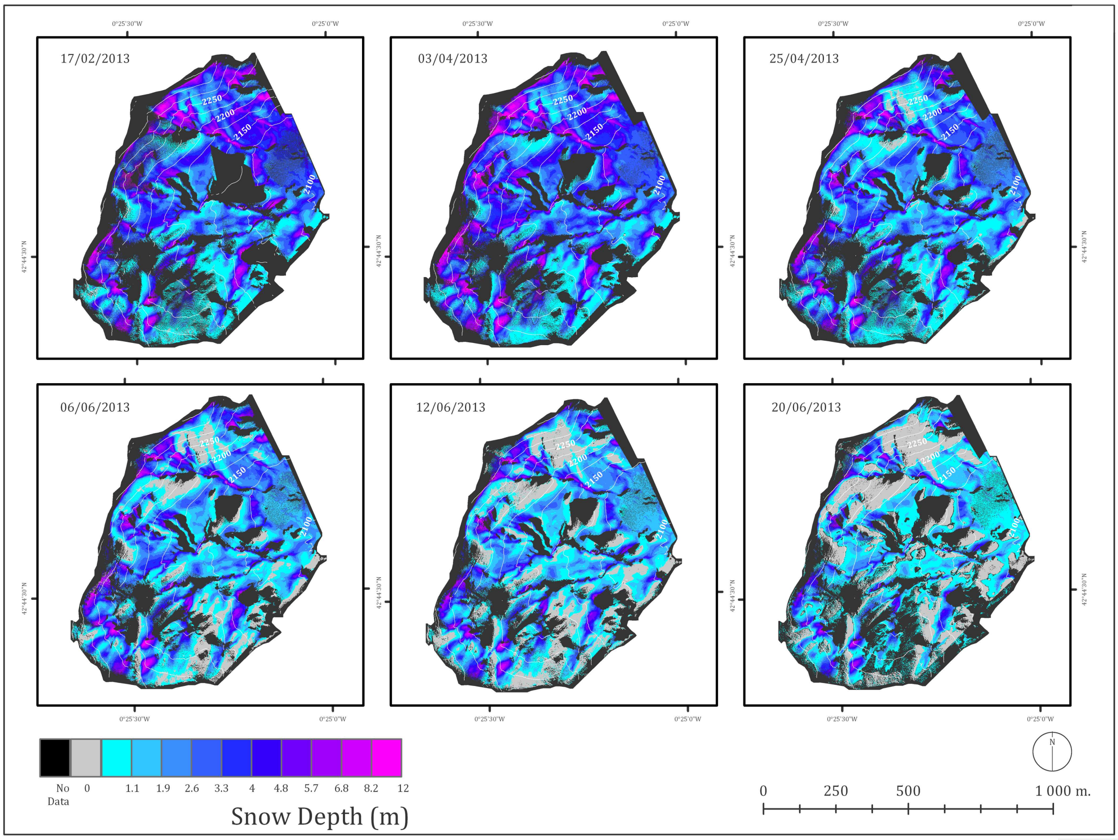


Figure 5 Snow depth distribution maps obtained for the six TLS acquisition~~s~~ dates of the 2012/2013 snow season.

Figure 6 Example of a sequence of four photographs for the 2012/13 snow season, showing the evolution of the snow cover.~~ed area evolution.~~

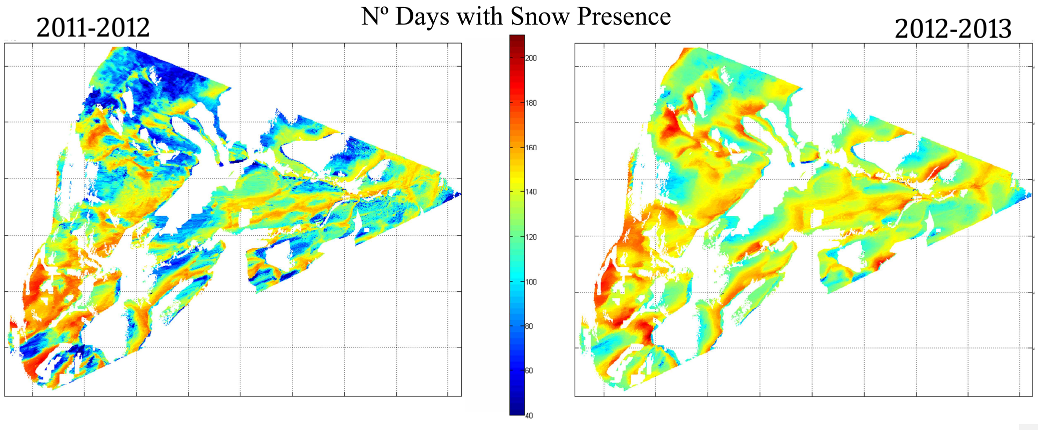


Figure 7 Number of days with snow presentce for each pixel for 2011/12 and 2012/13 snow seasons.

Tables:

		Air temperature (ºC)					
		2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Mean	**Annual**	5.13±7.73	3.50±6.88	4.17±6.11	5.26±7.02	5.08±6.69	Nan
	Accumulation	-1.15±5.69	-2.78±4.57	-1.71±3.44	-1.65±4.87	-1.66±3.69	-0.56±4.20
	Melting	5.80±6.60	2.79±4.79	5.51±4.07	7.23±4.86	4.45±5.12	7.58±6.00
Max	**Annual**	25.87	20.85	21.42	24.07	24.23	Nan
	Accumulation	7.89	10.69	10.20	10.98	11.62	11.39
	Melting	18.29	17.13	18.32	23.07	19.26	22.51
Min	**Annual**	-18.51	-15.26	-11.35	-15.24	-11.78	Nan
	Accumulation	-18.51	-15.26	-11.35	-15.24	-11.78	-14.97
	Melting	-9.33	-9.04	-3.71	-4.76	-8.20	-8.33

Table 1: Mean and standard deviation of air temperature for the five snow seasons for the annual, accumulation and melt~~ing~~ periods. Also are shown maximum and minimum air temperatures for the each period of the snow seasons (*Nan means no data observed during the period).

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	Relative Air Humidity (%)					
	2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Annual	59.9±18.9	70.1±17.1	68.8±17.3	64.8±19.2	65.9±18.5	Nan
Accumulation	67.1±18.1	70.5±19.3	72.7±15.8	62.8±22.2	71.3±18.3	61.0±20.8
Melting	57.1±15.2	74.4±14.5	68.7±15.9	63.9±15.8	69.9±14.1	62.9±15.65

Table 2: Mean and standard deviation of relative humidity for the five snow seasons for the annual, accumulation and melt~~ing~~ periods(*Nan means no data observed during the period).

	Atmospheric air pressure (mbar)					
	2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Annual	794.5±5.9	790.7±7.7	791.3±6.5	792.4±6.9	791.8±7.1	Nan
Accumulation	790.9±7.2	784.7±8.3	786.4±6.9	789.7±9.3	786.8±7.9	788.5±5.5
Melting	797.1±3.6	790.9±6.6	791.8±4.6	794.2±4.4	788.9±5.4	791.5±5.0

Table 3: Mean and standard deviation of atmospheric air pressure for the five snow seasons for the annual, accumulation and melt~~ing~~ periods.

	Depth (cm)	Ground Temperatures (°C)					
		2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Annual	**0**	Nan*	4.60±6.71	5.13±6.45	5.98±7.02	4.24±6.02	Nan
	5	Nan	4.35±5.67	5.61±6.52	6.06±5.52	4.66±5.12	Nan
	10	Nan	4.38±5.19	5.07±5.46	5.99±6.09	4.55±4.87	Nan
	20	Nan	4.26±4.66	5.01±4.62	5.08±3.26	4.51±3.88	Nan
Acc.	**0**	Nan	0,22±0,05	0.03±0.04	-0.26±0.87	-0.66±1.13	Nan
	5	Nan	0,69±0.12	0.11±0.08	-0.39±0.54	0.99±0.10	Nan
	10	Nan	1.10±0.16	0.31±0.18	-0.27±0.23	0.98±0.11	Nan
	20	Nan	1.34±0.19	0.94±0.06	0.39±0.08	1.57±0.17	Nan
Melting	**0**	Nan	1.21±3.49	5.53±6.41	7.87±6.41	4.57±5.46	Nan
	5	Nan	1.04±2.45	5.19 ±6.08	7.03±5.71	4.43±5.09	Nan
	10	Nan	1.06±1.78	4.15±4.68	6.46±5.32	4.15±4.79	Nan
	20	Nan	1.04±1.36	3.46±3.49	5.35±4.15	3.50±3.47	Nan

Table 4: Mean and standard deviation ground temperature for different depths for the five snow seasons for the annual, accumulation and melt~~ing~~ periods (*Nan means no data observed during the period).

	Surface temperature (°C)					
	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
Annual	Nan	1.29±7.83	2.44±7.06	3.26±8.14	3.26±7.71	Nan
Accumulation	Nan	-5.38±3.58	-4.18±2.65	-5.36±3.61	-4.32±2.99	-3.68±3.58
Melting	Nan	-0.09±3.44	3.75±5.16	5.95±6.02	3.47±5.96	6.64±6.67

Table 5: Mean surface temperature from the infrared sensor for the five snow seasons for the annual, accumulation and melt~~ing~~ periods (*Nan means no data observed during the period).

		Radiation ($W/m^2 day$)					
		2011/12	2012/13	2013/14	2014/15	2015/16	
Annual	**Global**	219.48±110.60	205.36±114.50	196.64±110.49	207.63±116.50	211.03±113.95	Nan
	Reflected	82.87±49.60	96.20±64.92	79.35±52.78	76.34±64.90	83.61±53.76	Nan
Acc.	**Global**	181.09±68.18	154.83±67.30	150.04±84.02	166.97±65.80	152.83±83.18	182.64±85.36
	Reflected	99.14±40.34	117.04±44.35	108.50±47.43	114.24±44.35	108.94±48.59	110.29±41.13
Melting	**Global**	245.37±120.56	289.59±114.10	283.33±102.80	287.65±117.15	278.71±114.37	301.07±107.57
	Reflected	103.11±67.15	169.56±60.28	114.83±61.10	90.51±60.28	120.06±67.30	104.28±66.7

Table 6: Mean global and reflected radiation for the five snow seasons for the annual, accumulation and melt~~ing~~ periods (*Nan means no data observed during the period).~~.~~

		Accumulated total precipitation (mm)					
		2011/12	**2012/13**	**2013/14**	**2014/15**	**2015/16**	**2016/17**
Ann	**Pcp** (mm)	Nan	Nan	Nan	1572	411	
Acc.	**SD** (cm)	14.74±14.60	145.61±52.3	148.54±41.60	55.90±36.50	81.42±31.67	Nan
	Pcp (mm)	Nan	Nan	Nan	454.35	147.22	114.44±73.80
Mlt.	**SD** (cm)	1.60±1.57	131.42±64.64	51.57±64.95	12.70±22.24	64.30±59.85	82.38
	Pcp (mm)	Nan	Nan	Nan	249.61	121.05	25.14±32.22

Table 7: Accumulated precipitation (liquid and solid) for snow seasons with observations available. Average snow depth values for accumulation and melting periods for the five snow seasons (*Nan means no data observed during the period).

Date		Mean SD (m)	Max SD (m)	SCA (%)	CV
Snow season 2011/12	22-Feb	0.46	5.53	67.2	1.35
	02-Ap~~b~~r	0.17	3.86	33.5	2.23
	17-Apr	0.56	5.34	94.1	1.07
	02-May	0.90	6.11	98.8	0.74
	14-May	0.21	4.47	30.9	1.90
	24-May	0.09	4.32	18.9	1.29
Snow season 2012/13	17-Feb	2.91	10.89	98.8	0.63
	03-Apr	3.19	11.20	100	0.56
	25-Apr	2.42	10.10	96.3	0.76
	06-Jun	1.98	9.64	86.4	0.86
	12-Jun	1.69	8.90	77.1	0.90
	20-Jun	0.76	7.97	67.0	1.35
Snow season 2013/14	03-Feb	2.16	10.20	96.0	0.59
	22-Feb	2.56	10.47	98.6	0.57
	09-Apr	2.54	9.72	89.0	0.65
	05-May	1.67	9.02	75.2	0.87
Snow season 2014/15	06-Nov	0.22	2.78	85.0	0.81
	26-Jan	0.74	4.88	89.3	0.85
	06-Mar	2.13	11.55	94.0	0.69
	12-May	0.67	7.75	56.0	1.21
Snow season 2015/16	04-Feb	0.82	6.20	91.1	0.63
	25-Apr	1.86	10.82	97.0	0.50
	26-May	1.16	7.81	74.8	0.70
Snow season 2016/17	20-Jan	1.26	6.33	93	0.72
	08-May	0.77	7.25	57.2	0.81

Table 8: Observed mean and maximum snow depth values, snow covered area (SCA, % of the total area covered by the TLS), and coefficient of variation for the observed snow distribution on the TLS survey dates.